Economic analysis of a target diameter harvesting system in radiata pine

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Abstract

Target diameter harvesting (TDH) is a forest management system in which all stems above a set minimum diameter are harvested on a periodic basis. There is evidence in the literature that TDH can achieve a rate of return on a similar scale to a clearfelling regime, with added benefits of regular cash flow from partial harvests, and preservation of non-timber values.

Economic analysis was carried out on 12 years of TDH using permanent sample plot (PSP) data from Woodside Forest, a 30ha plantation of radiata pine (*Pinus radiata*). The Woodside Forest management regime has a target diameter of 60cm, and a harvest cycle of two years. Economic analysis considered the option to partial harvest or clearfell every two years, and compared the outcome of each option in terms of land expectation value (LEV). Comparisons are made between regimes with different numbers of partial harvests, assessing the effect of TDH on stand LEV.

Results show that in three of four applicable stands, LEV reached a maximum at ages 30 – 32, (near the time when partial harvesting commenced), and reduced slowy with increased numbers of partial harvests. This shows there is a small opportunity cost associated with choosing TDH over a clearfell system. The effect of revenue from early partial harvesting operations on LEV was small as the majority of stand value is still in the standing crop. This limited the conclusions that can be drawn form this study due to the short time frame analysed.

The study was limited by a small dataset which did not accurately represent average stand values. Because of this, no attempt to quantify the value of the opportunity costs was made. Despite this, the results support the notion that TDH can achieve economic returns similar to clearfelling in radiata pine forests.

Key words: Continuous cover forestry, radiata pine, target diameter harvesting, Woodside Forest, natural regeneration, mixed-age forestry, partial harvesting, economic analysis

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1 Introduction

New Zealand forestry manages radiata pine (*Pinus radiata*) almost exclusively on a clearfell regime. At a global level, other harvesting systems such as single tree selection or patch cutting are used more frequently than in New Zealand, either because of forest biological constraints, environmental constraints, or to maintain other benefits and services provided by the forest system. This research looks at a selection harvesting system being implemented in a radiata pine plantation in New Zealand's Canterbury foothills.

The study site is a mature radiata pine plantation being managed under a target diameter harvesting (TDH) system; a method of continuous cover forestry (CCF). Harvesting takes place periodically, and all stems above a minimum target diameter are removed. The rationale for using a TDH system in preference to a clearfell system is in two parts; firstly, by harvesting the large trees whose value increment is small in proportion to their current standing value, the percentage value growth of the stand is maintained at a level acceptable to the forest owner. In this way, not only is cash flow provided from partial harvests, but a return on investment can be achieved on a similar scale to clearfelling. Secondly, harvesting under a TDH system extends the stand rotation and clearfelling is delayed or avoided altogether, which maintains non-timber benefits of the forest and mitigates the undesirable environmental effects of clearfell harvesting.

With the New Zealand forest industry facing increasing environmental constraints at harvest time, it is timely to consider alternative methods of harvesting that maintain the environmental values of the forest. There are very few examples of partial harvesting in radiata pine and just one involving TDH - Woodside Forest in Canterbury. When considering TDH in radiata pine plantations, the first question is one of economics; how do returns compare to the conventional clearfell system? Answering this question will allow forest owners to make clear decisions around the benefits and trade-offs associated with choosing to manage under a TDH system or a clearfell harvest system.

This report analyses 10 years of TDH in Woodside Forest, a 30ha radiata pine plantation. Economic performance is compared to conventional clearfell systems, and differences are reported in terms of land expectation value (LEV). Cash flow profiles and a sensitivity analysis is also reported.

2 Background and literature review

The distinguishing feature of any type of CCF management is the avoidance of clearfelling (W. L. Mason, Kerr, & Simpson, 1999). By avoiding clearfelling, non-timber benefits such as biodiversity and environmental values, soil stabilisation, improved water quality, carbon storage, and aesthetic and recreational values are maintained. CCF can also be economically attractive as periodic harvests provide an on-going cash flow.

CCF is not a new idea – it has been identified in the literature for well over a century – but there has been renewed interest and debate recently e.g. Lähde, Laiho, and Norokorpi (1999); Malcolm, Mason, and Clarke (2001); W. L. Mason et al. (1999). Pommerening and Murphy (2004) provide a good historical account of CCF and discussion of this renewed interest, primarily in European countries.

2.1 Target diameter harvesting

Perhaps the purest form of CCF is single tree selection. However this system can be difficult to implement. Marking trees for harvest requires high levels of skill, and is time consuming and costly. TDH or diameter-limit harvesting can offer a practical alternative to single tree selection (Miller & Smith, 1993). TDH involves a target diameter above which all stems are harvested on a periodic basis. “Strict” TDH is a removal-driven harvesting method that does not consider the condition of the residual stand, or regeneration. It has been justifiably compared to high-grading and shown to degrade the quality of the residual stand over time by retaining all poor quality stems and giving no consideration to competition for resources (Kenefic, Sendak, & Brissette, 2005; Miller & Smith, 1993). “Flexible” TDH involves the removal of stems above the target diameter, but also allows for some stand improvement cuts. The forest manager has the flexibility to remove stems of poor quality or high risk, and stems that are too close together preventing high value stems from reaching their full potential. In effect, flexible TDH can be seen as a compromise combining the management advantages of strict TDH with some of the safeguards of a single tree selection system (Miller & Smith, 1993).

The economic theory behind selective harvesting is well documented e.g. Klemperer (1996). In a clearfell regime, the economically optimum rotation age is the age at which the stand achieves the highest rate of return (ROR) on investment. For a selection harvesting system, this theory can be applied at an individual tree level; trees are removed on the basis of their individual ROR. In doing so, a ROR can be maintained at an acceptable level across the stand in perpetuity, so long as there is regeneration to provide future crop trees. At an individual tree level, financial maturity is reached when a tree's annual value increment as a percentage of its standing value first falls below the required ROR (Klemperer, 1996). This situation arises as trees become very large, making value increments small in proportion to standing value, or if a tree is malormed or suppressed and growing very slowly. Assessing all stems in terms of financial maturity ensures that resources such as growing space and available light and nutrients are continually made available to trees earning equal or greater than the required ROR (Miller & Smith, 1993).

To estimate a tree's value growth is not simply an estimate of volume growth, but also an estimate of any quality and grade changes that may occur through growing the tree for another cutting cycle. There are also possible release effects on the growth rate and rate of return of surrounding trees when one tree is removed in harvesting. These factors are virtually impossible to evaluate accurately and to attempt to do so would be very time consuming and costly. TDH is a method of applying these principals in a practical fashion; specifying a target diameter that will maximise the ROR of the forest, based on growth rates for a particular site and applicable log grades. The same theory can also be used to develop improvement cut guidelines to maintain the desired stand structure and ensure sustainable log yield.

2.2 Related studies

There is a growing volume of literature that discusses the advantages and practical issues of CCF and TDH (W. L. Mason et al., 1999; Sterba & Zingg, 2001; Tarp et al., 2005). Sustainable forest management was reviewed at the United Nations Commission on Economic Development (UNCED) summit in Rio de Janeiro in 1992 and this served as a catalyst for renewed interest in CCF (Pommerening & Murphy, 2004). Malcolm et al. (2001) discuss the practicalities of transforming even-aged conifer stands to more structurally diverse systems in Britain. It is concluded that successful transformation to irregular stands depends on adequate seed supply, and silvicultural systems that provide microclimates able to facilitate natural regeneration. For species that are intermediate in shade tolerance or are shade-intolerant, the creation of gaps to provide regeneration niches is important for regeneration of successional crop trees. These issues are particularly relevant to radiata pine which, though more tolerant than many other pines, is widely considered a shade-intolerant.

Even-aged radiata pine plantations comprise 90% of New Zealand's production forestry (Ministry of Agriculture and Forestry 2011). CCF systems have been used before in radiata pine plantations both past and present, but examples are few. Harry Kingsland of Nelson successfully implemented a partial cutting regime early in the twentieth century and claimed to have great success. An exchange of viewpoints on CCF in radiata in the New Zealand Timber Journal and Forestry Review (Anon., 1956a, 1956b; Baigent, 1956) show this topic was hotly debated at the time, and more recent articles by Benecke (1996) and Mason (2002) show this interest continues today. A more recent example of CCF in radiata pine is the Wardle family's Woodside Forest, which has been managed under a TDH system with claimed success in terms of economic return and retention of non-timber values. Woodside Forest provides the data for this study.

Bloomberg and Dickson (2003) carried out a feasibility study of partial harvesting in radiata pine stands in Canterbury, New Zealand. The study simulated several harvesting scenarios; a single clearfell at ages 25, 30, 35, and 45, as well as two TDH partial cuts at ages 25 and 35 followed by clearfell at 35 or 40. Results showed that the NPV for the rotation was highest for the partial cut scenario with final clearfell at age 35. This remained the case as partial harvesting costs were increased by up to 50% from clearfell costs. There were two significant weaknesses in this study; the growth modelling process used did not account for the release effects after partial harvests on the residual crop; and the growth model could only project 10 years, so model outputs were used to project further growth. Despite these weaknesses, the study provides preliminary evidence that radiata pine can be successfully managed under a TDH to an economic advantage. However, questions remain about the suitability of radiata to a TDH cutting system in perpetuity.

2.3 Suitability of radiata pine for continuous cover forestry

The dominance of radiata pine in New Zealand plantation forestry is due to its ability to provide an economic source of general purpose softwood (Lewis & Ferguson, 1993) and a suitability to a wide range of New Zealand sites. It has a long history of intensive plantation management in New Zealand, with well-established systems focused on maximising productivity. It is a relatively short-lived pine; the oldest cores from its natural range have been dated 250 years (Lewis & Ferguson, 1993), though this is exceptional. In New Zealand plantation forests it is seldom grown more than 30 years due to compounding effects of the time value of money on economic returns. It should be made clear here that rotation ages are dictated by stand level ROR; it is based on economic maturity, not biological maturity. Lewis and Ferguson (1993) report that stands as old as 50 years commonly achieve annual growth increments of 10 - 30 m^3/ha/year.

Management of radiata pine under a CCF regime would necessarily result in trees being grown to significantly longer ages than is typical for a clearfell operation – perhaps as old as 50 - 60 years. Woollons and Manley (2012) report that radiata pine can be successfully grown in rotations of 60 – 100 years without excessive loss in standing yield or senescence occurring. The majority of annual mortality rates in 140 old-aged PSPs examined were less than 2 per cent, and more than 80 per cent of mortality occurred in stems defined as very small or suppressed.

These findings support claims by John Wardle (pers. comm.) that trees are still showing rapid diameter growth in partially harvested radiata stands up to 40 years old in his Woodside Forest. John Wardle (pers. comm.) also claims there is a significant growth response in residual trees following the removal of neighbouring trees at harvest. Preliminary analysis of PSP diameter growth data from Woodside Forest supports these claims (Perry, unpublished data). In stands ranging in age from 30 to 40 years, stems show annual DBH increments as high as 24mm. Slow-growing stems show greater than 10mm/year increases in DBH in years following the removal of adjacent trees.

Growing trees to older ages under partial harvesting will very likely have some effects on the quality of timber produced. A significant issue in New Zealand is the high proportion of low-quality wood often present in fast-grown short rotation radiata pine, especially in the butt log portion of the stem. Low-quality corewood can fail to meet the stiffness requirements for structural timber and result in log downgrade (Xu & Walker, 2004). Wood stiffness and density increase with age; the rate of annual increase in fibre length normally stabilises around the 12^{th} growth ring (Lewis & Ferguson, 1993). In radiata plantations, these first twelve years coincide with rapid diameter growth resulting in a large core of significantly lower quality wood. In a partial harvesting system where trees are grown for longer and are larger at harvest, removed trees will contain a much higher proportion of high-quality outer wood. Further to this, if regeneration is achieved under a partial canopy, the first twelve years of growth are very likely to be slower and may be more directed toward height growth resulting in a smaller low-quality core in successive rotations. To date there is no research available on this topic.

3 Research Objectives

The focus of this analysis is the economic performance of TDH compared to a clearfell system in a radiata pine plantation. The analysis is based on real data and covers 10 years of TDH with a periodic harvest cycle of two years. Due to the short time period and small dataset, this is intended as a preliminary study to provide justification for further work investigating partial harvesting in radiata pine.

This research addresses the question; what is the opportunity cost of spreading harvest revenues over an extended period of time using TDH versus clearfelling?

This question is addressed by assessing the effect of up to five TDH harvest operations on forest investment returns in terms of LEV. Cash flow profiles and sensitivity analysis provide further insight into the economic advantages and potential risks associated with TDH in radiata pine.

4 Methods

4.1 Site and regime description

The study site comprises approximately 30ha of radiata pine which is currently being managed under a TDH system by owners and managers Dr John and Rosalie Wardle. The forest is located in the Canterbury foothills, 43º15'46" South 172º03'24" East. The forest has an average altitude of 450m, receives an annual rainfall of 1300mm, and has a cool winter. Winter snowfalls of 120mm are common, with occasional falls over 1m.

The radiata plantation was established in small stands each year from 1973 to 1995. All stands were initially planted at 1500 stems per hectare. Pruning was done in two or three variable height lifts to achieve a small defect core. Stands were thinned in two operations down to a target final crop stocking of 500 stems per hectare. Most of the pruning and thinning was done by the Wardles themselves, and most of the early thinnings were extracted and milled on site for farm use or firewood. One attempt at commercial production thinning was made, but this was not profitable.

As the stands approached normal harvest age, the Wardles considered partial harvesting. John Wardle (pers. comm.) could not see the sense in clearfelling stands when there was such a wide variation in log size. Instead he decided to selectively harvest the large trees to provide cash flow while also reducing competition in the residual crop which is left to grow on. He applied this theory by setting a target diameter of 60cm, based on the optimum size for peeler mills. Harvesting of each stand takes place every second year. All trees above 60cm are removed, and consideration is also given to the residual crop, reducing competition or removing stems showing poor form.

Harvesting is done in autumn when the bark is tight to minimise damage to the residual crop. All harvesting is done by a two-man ground-based crew. Stems are directionally felled, and extracted to roadside or small landings with a small Clark 666C skidder. Cartage requires self-loading trucks. An added bonus of harvesting at frequent intervals is that it provides the opportunity to recover windthrow.

The Wardles take a very hands-on approach to their forests, carrying out regular control of gorse and blackberry and personally selecting stems for harvest. The more open stands are also used for grazing stock. In parts of the stand where harvests have sufficiently increased light levels, there is abundant regeneration. Where necessary, regeneration is thinned to a target level of 3000 stems per hectare, with the view that many will not survive the periodic harvesting operations. Dr Wardle reports second rotation regeneration is showing excellent form with very little taper allowing pruning to 6.5m in one or two lifts with a small defect core. Dr Wardle is of the opinion that regeneration will make it possible to continue partial harvesting in perpetuity without ever clearfelling.

4.2 Data collection

Data were analysed from 6 permanent sample plots (PSPs). The plots were transect lines 62.5m x 8m giving an area of 0.05ha each. Plot lengths were not adjusted for slope. The data included diameter measurements at 140cm above ground level (DBH), recorded either four or five times at uneven intervals between the year 2000 and 2010. The diameters of all trees in all six plots were measured in December 2012 as part of this study. Plot descriptive statistics were recorded such as slope, aspect, and proximity to edges or any major windthrow events (Table 1).

Table 1. Plot statistics and descriptions

Stand ID (Year planted)	Final crop stocking (stems/ha)	Stems removed per year (stems/ha)	Plot description
1974	322	17.2	2 plots, both on or near ridge top, 5º average slope, Northeast aspect
1975	431	26.4	28° slope, Southerly aspect, high proportion of edge trees.
1976	509	24.3	34º slope, Easterly aspect, starting from ridge top.
1978	368	13.5	12° slope, edge plot in stand with high incidence of wind throw. Poor quality stems. Southerly aspect.
1983	557	32.2	21 ºslope, Southwest aspect, high stocking

The heights of all trees in the plots were also measured in December 2012 using a Vertex hypsometer. Further heights of trees adjacent to the PSPs were measured to give a total of 30 measured heights per stand to provide a large enough sample for the development of stand-specific height diameter relationships.

All plots were cruised for stem quality by recording running heights below which predefined quality standards are satisfied (Figure 1). Quality standards are broken into three domains, and stems are assessed for each domain independently (Table 2). Where there was a fork above measurable height, the diameters of each fork were estimated. Data were entered into Plotsafe version 1.5.2.0 for use in YTGen version 2.9.8.1 yield estimation software (Silmetra Ltd, Rotorua, New Zealand). It was assumed that all stem features have remained the same over the past 12 years.

Table 2. Codes and descriptions used to cruise stem quality in the PSPs

Code	**Description**
Branch size	
0	Pruned
7	Max branch diameter <7cm
14	Max branch diameter <14cm
99	No maximum
Sweep	
8	Sweep < 1/8th SED over 6.1m
S	Sweep < 1/4 SED over 6.1m
3	Sweep < 1/3rd SED over 6.1m
1	Sweep < SED/1
X	sweep > SED/1
K	Kink < 0.5m
W	wobble > 0.05m over 6.1m
R	waste
Features	
F	Forked
BT	Broken top
D	Damage (from harvesting operations or wind throw)
Df	Deformation

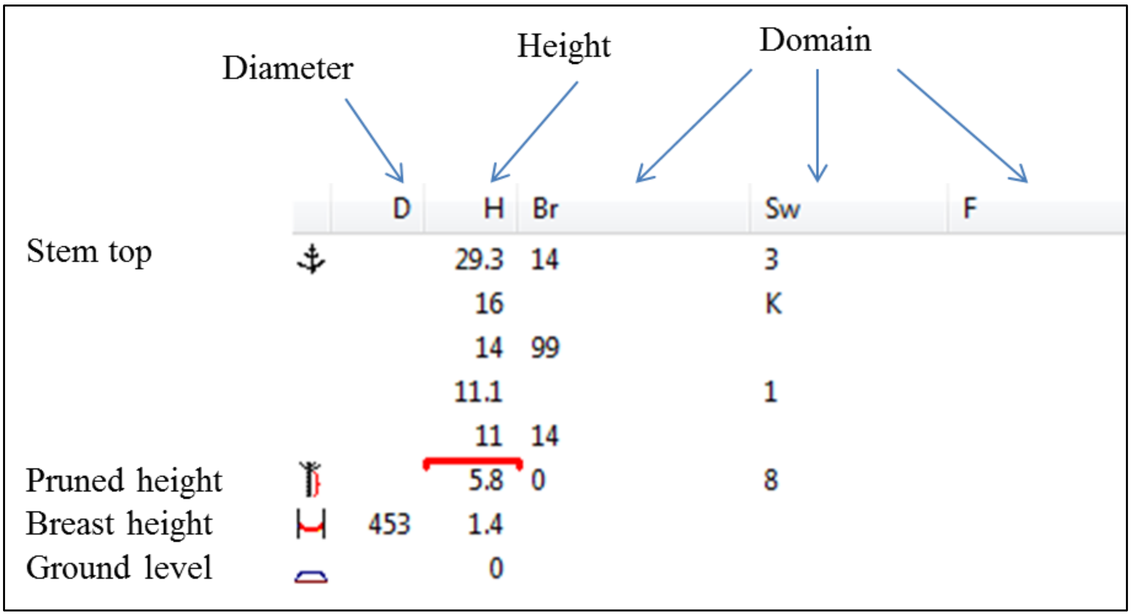

Figure 1. Example of stem quality data in PlotSafe (2012) showing heights codes for stem features defined in Table 2.

Harvest volume records were provided by John Wardle (pers. comm) for every TDH operation, broken down by log grade for each stand. Some removals of stems from the PSPs during TDH were recorded, but these records were incomplete. Using what records were available combined with physical evidence from remaining stumps and standing trees, it was possible to identify all stumps of removed trees in the PSPs and determine the year of harvest through a process of elimination.

A pre-harvest inventory from the year 2002 including DBH, heights and quality estimates of the stems selected for the first TDH operation was provided. This is the only height data available from when the site was fully occupied.

4.3 Adjusting DBH and height

To calculate the value of harvested stems or the value of the standing crop requires estimates of DBH, height, and quality for the time of harvest. However, since DBH measurements were taken at uneven intervals that do not coincide with harvest times, these data needed to be adjusted to match harvest times. Harvests take place in each stand every second year in April/May, but for this analysis harvest was assumed to take place on 30th June, the end of the tree growth year in New Zealand (Jackson, 1975).

Seasonal changes in temperature, rainfall, and sunlight hours give rise to differential growth rates in radiata pine throughout the year. Therefore, when adjusting DBH measurements to match harvest dates, the size of the adjustment depends not only on the growth rate at the time, but also on the time of year over which the adjustment takes place. DBH data were adjusted to match the two year harvest cycle using the following method:

1. For each period between DBH measurements, a seasonal growth rate was calculated by dividing the total growth increment by the number of full growing seasons in the interval. A growing season is defined as 1st July to 30th June, with each month representing a proportion of a growing season based on a growth distribution described by Tennent (1986) for the Otago Coast region. For example, the period from 1st of January to 30th of June contains 0.408 growing seasons.
2. A two year period between harvests often included growth from more than one measurement period, meaning growth over the two years was at more than one calculated growth rate. Therefore, DBH increment was calculated by summing the products of the proportion of growing seasons in each measurement period multiplied by the growth rate in that period. DBH adjustments were done individually for each stem.
3.

Table 3. Proportion of annual growth per month (%). Note 12 months may not equal 100% due to rounding.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Otago Coast	13.9	12.3	8.6	2.2	0.8	3	5.6	7.9	9.2	10.4	12.1	13.4

Height growth of trees was estimated retrospectively for the past 12 years. For standing trees, height growth was assumed to follow a curve in constant proportion to a site-specific height-age curve estimated using the radiata pine calculator (NZTG, 2003). For example, if a tree's measured height is 90% of the corresponding height-age curve value at its current age, it is assumed it was always 90% of the height-age curve value at any age. This avoids the inaccuracy that arises when using stand level height diameter relationships to estimate individual stem heights.

There was no height information for harvested trees, so height at time of harvest was estimated using a stand-specific height diameter relationship developed from 30 trees from the PSPs and adjacent areas. Height diameter relationships were developed using the Petterson (1955) equation:

$$\text{Height} = 1.4\ (b + a/\text{DBH})^{-2.5} \qquad 1)$$

Height growth prior to harvest was then calculated in the same way as standing trees, by assuming a constant proportion to a site-specific estimated height age curve.

4.4 Estimating yields

With a full set of DBH and height estimates for the 30th of June from 2002 to 2013, it is possible to estimate clearfell and partial harvest yields using the YTGen software package. YTGen software combines stem growth and quality data with log bucking algorithms to simulate log merchandising. Outputs are in the form of log yield tables by log grade. A simple cut plan was specified in YTGen based on grades usually cut at Woodside Forest (Table 4). In partial harvesting systems cut plans are normally limited to only a few log grades due to low volumes, small skid size, and machinery available for fleeting. Full log grade specifications are given in Appendix 1.

Log prices in Table 4 were based on prices received for the 2012 and 2013 TDH yields (J. Wardle pers. comm), and found to be very similar to current 12-quarter average prices (MPI, 2013)

Table 4. Log grades used in generating yield tables using YTGen software, and log prices used as a base case in economic analysis

Grade	NZ$/tonne (at mill door)
Chip	42
Export	70
L20	75
L30	85
PP	180
PS	145
S1P	125
S20	80
S30	95

Because it is unknown how TDH will affect future growth of the stand it is not possible to accurately project yields and revenue from TDH indefinitely. Therefore, any economic analysis of Woodside Forest must be over a defined rotation length, and needs to include the value of the standing forest at the end of the rotation since this will represent a significant proportion of the stand value. The value of the standing crop is represented by a clearfell yield estimated from PSP data for each stand.

For the analysis, it is assumed that the decision to partial harvest an grow on, or clearfell is made every two years and each decision is independent (Figure 2). If the decision is to clearfell, the rotation terminates and LEV can be calculated. If the decision is to TDH, some revenue is generated, and the residual crop is grown on for two years until the next decision point. For this study the cycle is repeated six times over the 12 year dataset, with the decision in the sixth cycle always to clearfell so that the value of the current standing crop is included in the LEV. At each decision point, the outcome of both decision options, TDH or a terminating clearfell, is evaluated.

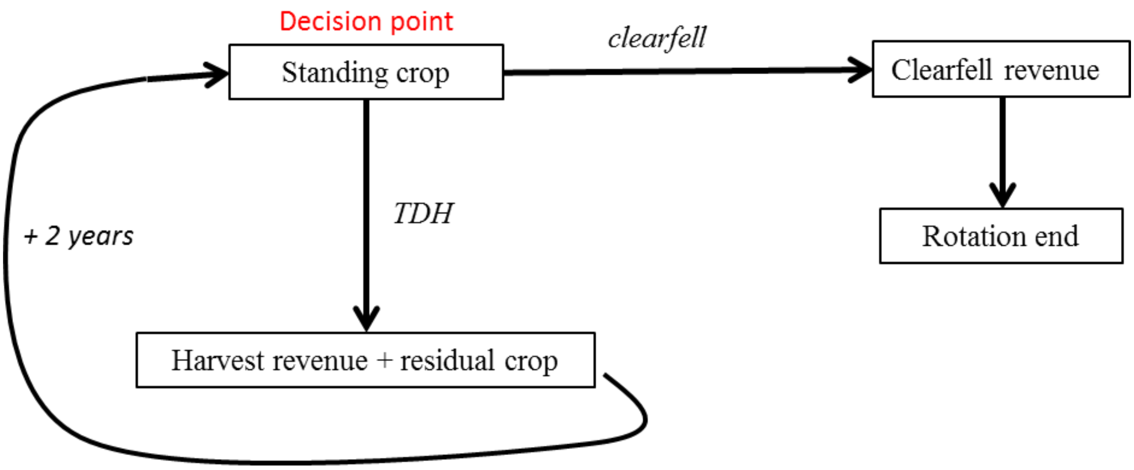

Figure 2. Flow chart of the decision to clearfell or TDH, made every two years in the analysis

To assess the effect on LEV of choosing TDH in preference to clearfelling, an LEV estimate is calculated at every decision point. The LEV includes revenues from all TDH operations up to that point, plus the value of the standing crop at that final decision point. This allows comparisons between a single clearfell regime, and up to five partial harvests followed by a clearfell.

Calculating LEV at each decision point required two yield estimates for each stand every second year:

1. A clearfell yield to represent the value of the standing crop.
2. A residual stand yield. i.e. a clearfell yield after the stems that were harvested that year have been removed.

The difference between these two yields represents the volume removed under TDH that year. These yield estimates were then used with log price estimates to calculate TDH and clearfell harvest revenues for use in discounted cash flow analysis.

4.5 Economic analysis

Discounted cash flows were used to calculate the net present value (NPV) of regimes with differing numbers of partial harvests. All regimes assumed the same establishment and silvicultural costs (Table 5). The total of all costs prior to harvesting beginning will have no effect on the comparison between TDH and clearfelling as they are the same for each regime. Roading costs are assumed to be the same for clearfell and TDH, and are assumed to be incurred in full in the year prior to the first harvest operation.

The rotation length increases with increasing numbers of partial harvests, so land expectation value (LEV) is used to compare regimes. LEV normalises rotation length by calculating the present value assuming perpetual rotations. LEV is calculated using equation 2.

$$LEV = NPV \times \frac{(1+i)^n}{(1+i)^n - 1} \qquad (2)$$

Where

NPV = net present value

$i =$ discount rate

$n =$ rotation length (years)

Table 5. Base case regime costs and discount rate. A full road network is assumed to be constructed in the year prior to the first harvest (H-1).

Year	Operation	Cost $/ha
	Annual costs	$50
0	Site prep	$100
0	Planting /spray	$1,200
5	1st Pruning	$500
7	2nd Pruning	$700
8	Thinning	$500
12	Thinning	$500
H-1	Roading/landing	$2,500
	Discount rate	7%

Harvest costs for TDH were assumed to be 25% higher than clearfell costs (Table 6). This is based on the author's discussions with John Wardle (pers. comm) and the logging contractor. Clearfell harvest rates are based on regional contractor rates for ground-based harvesting on moderate hill country. Transport costs represent an average of actual costs incurred in 2012 and 2013. Other costs are for harvest management and log sales costs.

Table 6. Harvest costs for clearfell and TDH harvest operations

	Clearfell costs ($/t)	TDH costs ($/t)
Harvest	30	37.5
Transport	25	25
Other	5	5
Total	60	67.5

Sensitivity analysis was carried out to assess the effects on NPV of up to a 30% increase and decrease in harvest costs, transport costs, and roading costs, as well as log prices and log yields, and investment discount rate.

The cash flow profile of a single stand with five partial harvests is compared to that of a single clearfell regime for the same stand. This comparison highlights the difference between the two regimes from a cash flow point of view rather than overall economic return from the investment.

5 Results

5.1 Investment analysis

Figure 3 shows the estimated LEV for each stand with differing numbers of partial harvests. The 1974, 1975, and 1976 stands show similar trends; a maximum LEV achieved between age 30 - 32, followed by a declining LEV thereafter with increasing numbers of TDH. The decline in LEV with increasing numbers of partial harvests shows that in these stands there is an opportunity cost associated with using TDH to spread forest revenues over time and delay the final clearfell.

Neither the 1978 nor 1983 stands have reached a maximum LEV yet (Figure 3). LEVs in these stands are negative over the whole period, indicating the investment does not achieve the 7% discount rate. The trend in the 1978 stand is also quite different to the three older stands in that NPV increases with increasing numbers of TDH at a steady rate. The only point of difference in this stand is that the TDH harvest volumes are quite regular between years, while in the older three stands they are highly variable. The trend in the 1983 stand is also a steady increase in LEV, though this is not unusual considering it is only 29 years old at the end of the period which is younger than the likely age of maximum LEV.

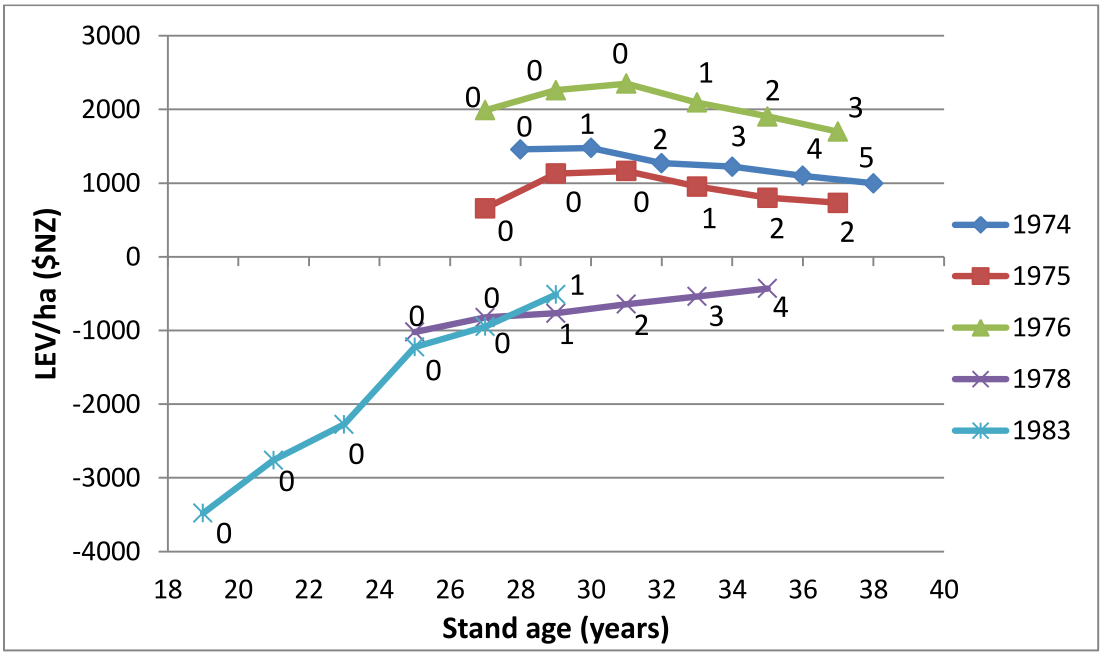

Figure 3. LEV (NZ$/ha) for the five stands examined under differing levels of TDH. LEV is calculated for each point independently using costs and revenues from all prior TDH operations combined with the value of the standing crop at that age. The numbers indicate the number of TDH operations prior to that age.

The range in LEV between stands is as high as $2,500 (Figure 3). This high range is likely to be a function of site quality (a brief description of plot site quality is given in Table 1). All but one of the LEV curves in Figure 3 are based on data from a single plot, so site variation between plots so site variation leads to marked variation between stand results when scaled up to a per hectare level. In the context of this study, the range in LEV value between stands is not important; it is the change in LEV within stands with different numbers of partial harvests that is of interest. However, following these results the representativeness of each plot was investigated further in terms of estimated harvest volumes and actual harvest volumes.

The graphs in Figure 4 compare harvest volumes estimated from plot data with actual harvest volumes recorded by John Wardle (pers. comm.). In all stands except the 1983 stand, the plot estimate yields are more variable and significantly higher than the actual harvest yields. This indicates that while plots are showing the range in site productivity across the estate, the plots are not very representative of their individual stands. This is supported by the author's field observations; all plots are in relatively favourable areas of the stands, with no representation of gully bottoms or the steeper parts of the stands. The plots are also all easily accessible for harvest, which may have had an influence on deciding which stems to harvest or whether or not it is possible to recover windthrow.

The non-representative nature of the plots means the absolute values of LEV shown in Figure 3 are likely to be over-predictions of stand value, but this will not affect the trend with respect to time of the LEV curves. Again, in this case it is the shape of the LEV curve versus stand age that is of most interest since it shows any change in LEV with increasing numbers of partial harvests.

The 1974, 1975, and 1976 stands have had different numbers of partial harvests and show high variability in partial harvest volumes, but show fairly smooth and similar LEV curves (Figure 3 & Figure 4). This suggests that the number of TDH harvests and the revenue they generate are having a small effect on the LEV curve over this period. This is logical in this situation. For example, after just one partial harvest, most of the value contributing to the LEV is in the value of the residual standing forest. As the number of partial harvests increases, the impact of their revenue on the LEV of the regime will increase relative to the value of the standing forest. The reason for this is that rotation length is extended with more TDH operations, increasing the effect of the time value of money on the value of the residual standing crop. With enough TDH operations, the discounted value of the standing crop will tend toward zero.

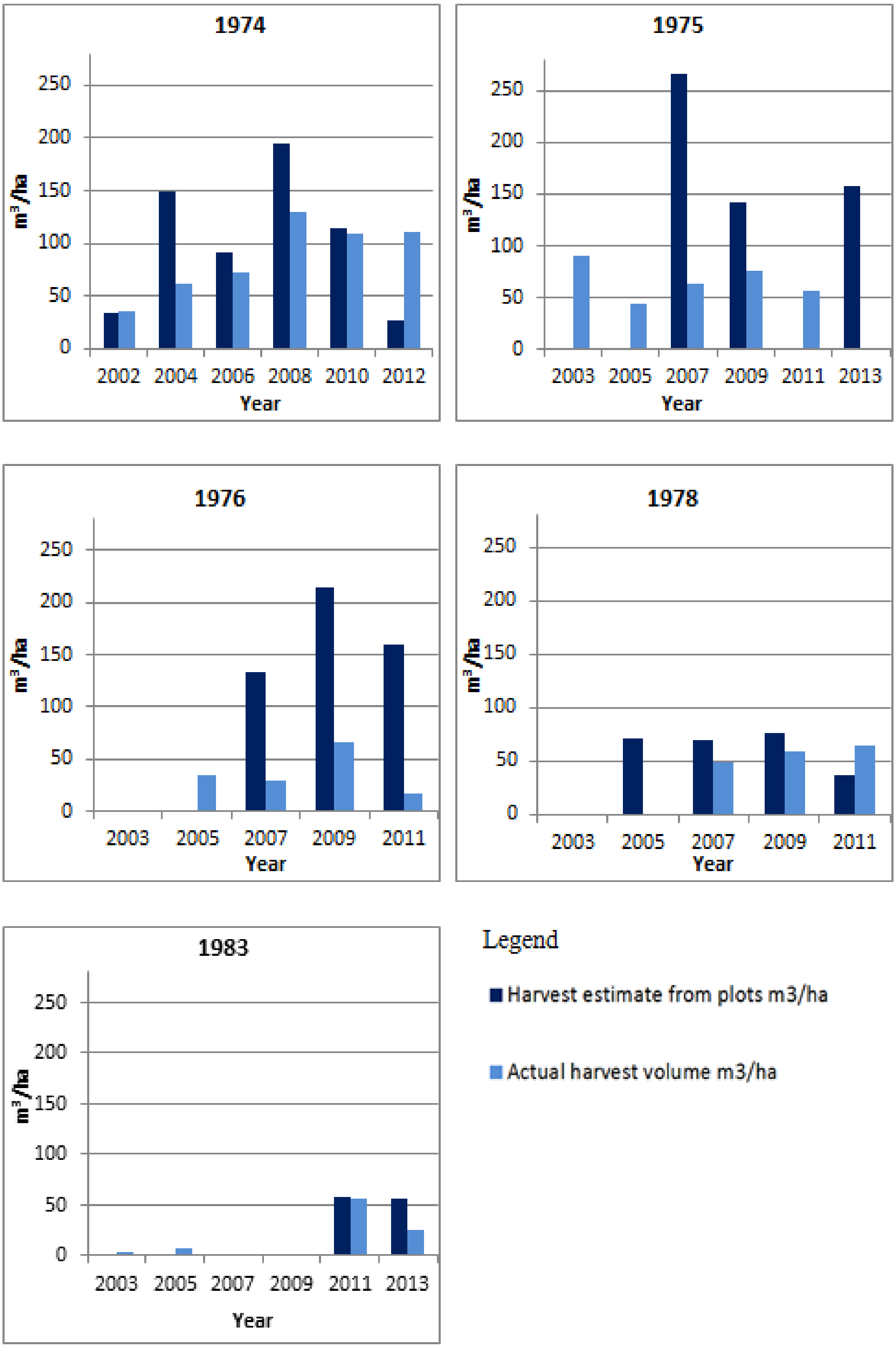

Figure 4. Comparing TDH harvest volumes estimated from PSPs with actual volumes from TDH harvest records.

5.2 Cash flow profile

Figure 5 shows the cash flow profile for the 1974 stand with five TDH operations plus the value of the residual standing crop at age 38. As shown in earlier results, the values are likely to be overestimates due to plots in this stand being in favourable areas. However, the figure illustrates clearly the differences between clearfell and TDH in terms of cash flow; a large single revenue versus a smaller biannual revenue stream that continues over ten years. The high variability in the TDH cash flow reflects the high variability in TDH volumes estimated using PSP data (Figure 4). Actual revenues would be more regular and are likely to be smaller, as would the actual clearfell revenue. It is not possible to calculate what the actual clearfell revenue would have been so the comparison with actual cash flow is not made.

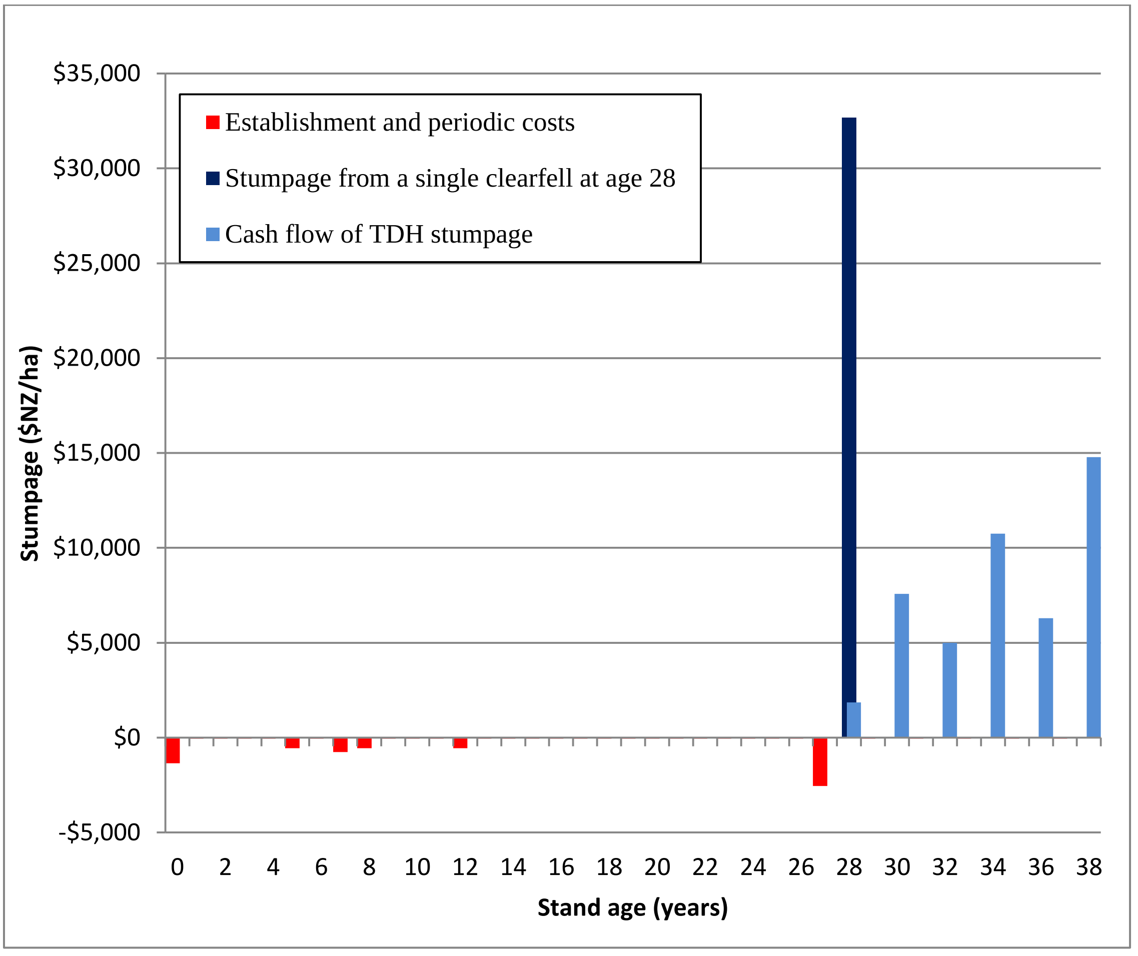

Figure 5. The cash flow profile predicted from PSPs in the 1974 stand with under the base case regime with five TDH partial harvests compared with a single clearfell. Note that the annual cost of -$50 is almost indistinguishable.

5.3 Sensitivity Analysis

The sensitivity analysis (Figure 6) shows the effect of up to a 30% decrease or increase in yields and economic inputs on NPV in the 1974 stand with five TDH operations. NPV is most sensitive to log prices and discount rate. Changes in log yield also have a significant impact, while harvest and transport costs have less effect. The cost of roading, incurred in the year prior to the first harvesting, has a very small effect on NPV.

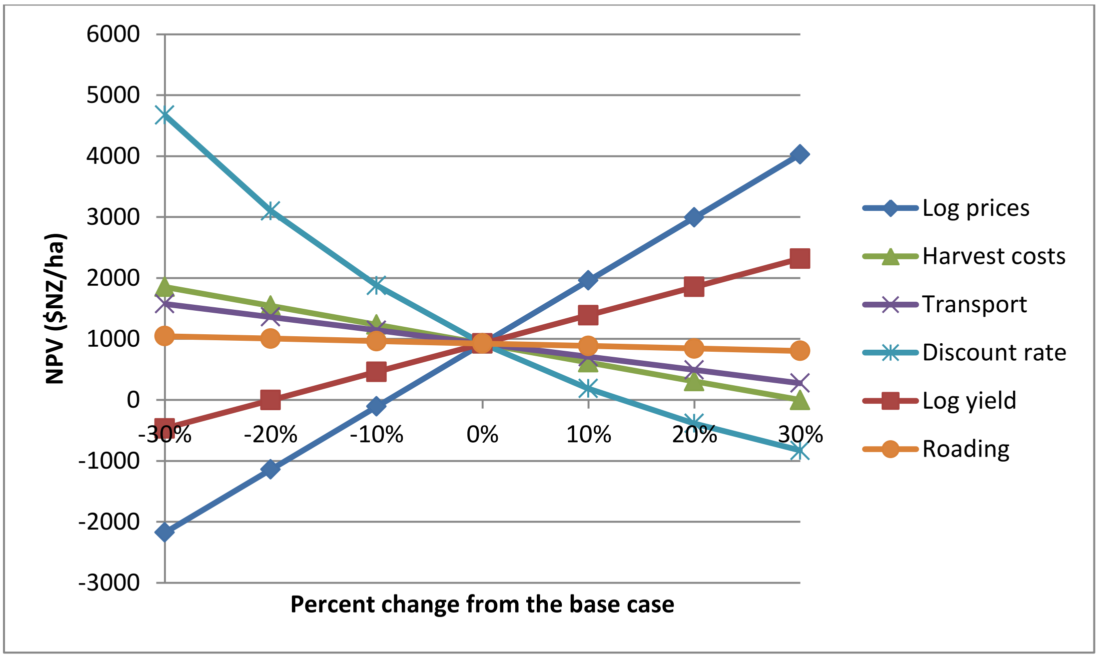

Figure 6. Sensitivity analysis of the 1974 stand NPV with five TDH operations

6 Discussion

6.1 Data limitations

There are two major limitations regarding the data in this study; the quantity and nature of data available and the length of time spanned by the TDH operation. A total of six plots across five stands meant that the analysis is not accurately representing true stand values of TDH or clearfell volumes and revenue, and this was clearly demonstrated in the results. For this reason, it is not very useful to quantify the opportunity cost associated with TDH in terms of a dollar value since the absolute values are probably incorrect. However, since both clearfell and TDH LEVs are calculated from the same data source, comparisons between the two are valid.

The lack of a control treatment was also a data limitation. The analysis considers increasing numbers of TDH with increasing stand age, but does not consider a clearfell-only regime past the age at which TDH was first implemented, as the stand is no longer complete from that point. A control treatment would involve plots with no partial harvesting to allow estimation of clearfell revenue at any age.

The length of time covered in the study was restricted to 12 years of TDH with five partial cuts and a final assumed clearfell (to allow estimation of standing crop value), as this is the extent of TDH management at Woodside Forest. Current growth models available for New Zealand radiata pine are focussed at stand level, and are not suitable for modelling partial harvest systems. They lack the capacity to deal with release effects and regeneration in the residual crop. Using real data ensured that the effects of stem removal on the residual crop were captured in the results, but means the study was limited to the level of TDH that has actually been completed to date. Since the results show that with low numbers of TDH operations the revenue generated from TDH has only a small effect on the LEV, this limits the conclusions that can be drawn from this study. Under a perpetual TDH system with no clearfell the LEV would be the sum of discounted cash flows made up of annual and periodic costs and perpetual periodic revenues from partial harvests. This study has shown that TDH for 10 years can provide an ROR similar to clearfelling; it cannot say whether a TDH regime can keep the LEV at acceptable levels out to a time when the influence of the standing forest on LEV is negligible. Answering this requires either modelling or observing the future of a stand under TDH until it reaches a sustainable state when volume growth increment equals harvest removals.

The regime analysed in this study is not necessarily optimal; the study was based on real data, and therefore dictated by what Dr Wardle has implemented in Woodside Forest. The diameter limit of 60cm was based on the optimum size for the peeler mills he intended to supply, not based on any growth function or stem economic optimisation. To base the diameter limit on the economic theory of TDH (section 2.1) would require estimating value increment as a function of stem diameter. This would need to account for wood property changes with diameter, as well as size and quality thresholds in the log grade specifications. A change in the diameter limit could have a significant effect on the LEV of the regime as it is likely to change the age at which harvesting begins. Earlier revenue streams would not only have an impact on LEV but could be more attractive to forest owners as there is a shorter wait between capital investment and positive cash flow.

The two year time interval between stand TDH operations at Woodside Forest was chosen to allow some harvesting and cash flow every year. Longer periods between harvests would mean greater harvest volumes and may reduce harvesting costs per m^3. In the Wardles' case, the cost of a two-man crew with a small skidder is not likely to change with the volume extracted, but if harvests involved more complex systems with greater moving and setup costs the effects would be much greater. The other trade-off is that the longer that trees above the diameter limit are left in the forest, the more impact they will have on stand economic returns due to their lower ROR, and because they reduce the rate of return of smaller trees by competing for resources. The optimum harvest cycle will therefore be a function of harvest system costs, stand growth, and the owner's cash requirements.

Roading costs are often presented as a barrier to partial harvesting because roading can be a very expensive part of the harvest operation and delaying revenue through partial harvesting increases the payback period. However, the results of this study show that LEV is weakly sensitive to roading costs, and is far more likely to be affected by log prices and log yield. This is because roading costs are incurred late in the rotation and are therefore heavily discounted in investment analysis. Despite this, roading costs can still present cash flow problems as high investment is required prior to harvesting commencement. This will most likely only be a barrier to some small forest owners with limited cash availability.

6.2 Discussion of results and implications

The economic analysis in this report does not take into account one of the primary advantages of partial harvesting; the indefinite preservation of non-timber benefits such as water quality, biodiversity values, soil stabilisation, aesthetic appeal, and carbon storage. LEV only considers costs and revenues from timber products. Economic values placed on non-timber products and services are usually non-market estimates and are not realised in actual financial returns. As a result they are usually left out of investment analysis and regime decisions (Klemperer, 1996). The resulting optimal forestry regimes do not place any importance on maximising non-timber benefits, and usually result in their loss through clearfell harvest operations. If there is ever a time when non-timber benefits are recognised in economic terms, either through payment or penalty for their loss, the economics of partial harvesting systems such as TDH will become more favourable. Plantation forestry is under constant pressure to comply with ever-tightening environmental standards and a situation where continuous cover is rewarded and/or negative impacts of clearfelling are penalised is possible. This provides strong motivation to further investigate the potential of TDH to provide economic returns while maintaining non-timber benefits indefinitely in radiata pine plantations.

Participation in New Zealand's Emissions Trading Scheme (ETS) has the potential to significantly impact forest profitability. Kyoto compliant forests can earn carbon credits for carbon sequestered as the trees grow. These credits can be traded to carbon emitters, providing early cash flow. A significant amount of these credits will need to be paid back at the time of clearfell harvest as sequestered carbon is deemed to be emitted. Manley and Maclaren (2010) have shown that higher carbon prices favour longer rotations under a clearfell regime due to the effects of compounding interest earned on revenue generated from carbon credits sold throughout the rotation, and the delaying of carbon liabilities at harvest. There is potential for 'carbon forestry' to improve profitability of partial harvesting systems for similar reasons; extending the rotation is inextricably a part of TDH. But further to this, if partial harvesting is carried out such that carbon sequestration equals carbon emissions due to harvest, the level of carbon on site will be approximately constant indefinitely. This means that any carbon credits traded up to the sustainable level will never have to be paid back so long as the forest is not clearfelled. There will remain however a carbon liability of unknown size if the forest is ever clearfelled or destroyed. The analysis in this report only spans 12 years of TDH and it is not yet known what level of carbon can be retained in perpetuity if, in fact, a sustainable level is reached at all.

Although there is no reason to suggest TDH may be practically limited to small scale forests such as Woodside Forest, there are reasons why it may be more appealing to small forest owners. Forests on farms and lifestyle blocks can provide shelter for stock, erosion control, as well as aesthetic appeal and recreational values. They may also often include only a few age classes, which under a clearfell system provide irregular large revenue sums and potential tax problems. Small scale forest owners may well place higher value on both the non-timber benefits, and the provision of regular cash flow. With approximately 1750 small forest (<500ha) owners in New Zealand with forests approaching maturity (MAF, 2011) it is very timely to present this analysis of TDH, and carry out further studies to investigate alternatives to the default clearfell system.

6.3 Further work

Further research and experiments are needed to substantiate the findings in this analysis and assess the effects of TDH beyond 12 years. Future analysis of Woodside Forest would allow analysis of how greater numbers of partial harvests affect LEV. This would also provide some preliminary assessment of the transition phase from the first rotation to the regenerating crop.

The establishment of the second rotation crop is an issue that needs to be addressed. Will natural regeneration occur sufficiently under the partial harvesting system? If so, how will this need to be managed to ensure the structure and quality of the next crop? These questions can only be answered through the implementation of partial harvesting and experimentation with management methods. Woodside Forest provides an opportunity to monitor this.

Woodside Forest was established in even-aged stands, but through continual partial harvesting and natural regeneration the forest structure is changing into a more mixed age forest. John Wardle (pers. comm) is of the opinion that while clearfelling to re-establish a stand will never be necessary, there may be a ‘harvest gap’ between the last of the original stand being harvested, and the first of the regeneration reaching the target diameter of 60cm. However, as partial harvesting continues through the second crop, stands are likely to become more variable in stand structure, eliminating future harvest gaps. How this change in stand structure will affect partial harvest volumes needs to be evaluated.

Future work should address the shortcomings in this analysis by using a much larger dataset representative of whole stands, and maintaining a control treatment with no

TDH. TDH parameters such as the diameter limit, time between partial harvests, and improvement cut guidelines should be well defined and, if possible, based on the economic theory described in section 2.1. Experiment design and data collection should be planned with the view to developing growth models that capture the effects of partial harvesting on the residual crop and the regeneration of subsequent crops. Accurate regular DBH and height data are essential. Some way of defining release from competition through the removal of neighbouring trees should be devised to assess and potentially model the effects of partial harvesting on the growth rates of the residual crop.

7 Conclusions

Results from Woodside Forest show that TDH is able to provide economic returns to the forest owner on a similar scale to clearfelling for up to five partial harvests. In three of four applicable stands, there is a small opportunity cost that increases with increasing numbers of partial harvests. Due to the small number of plots and their misrepresentativeness of stand values, no attempt was made to quantify the opportunity cost in terms of an economic loss on investment value of stands.

The effect of revenue from partial harvests on LEV is small in initial partial harvests due to the majority of the stand value being retained in the standing crop. As the length of time a stand is managed under a TDH system increases, the influence on LEV of the standing crop will be smaller, and the influence of revenue from partial harvests will be greater.

LEV of a TDH regime is most sensitive to the discount rate, log prices, and log yield. Harvesting costs and transport costs had less influence, and changes in roading costs (incurred in full in the year prior to the first partial harvest) had very little effect. Participation in the ETS has the potential to increase the profitability of TDH by providing early cash flow and delaying the time liabilities are incurred from harvesting.

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Appendices

Grade	Priority	Min SED (cm)	Max SED (cm)	Max LED (cm)	Lengths (m)	Conditions
PP	1	35	99	99	2.6,5.2,7.8	Br<1 Sw:8 no features or damage permitted
PS	2	35	99	99	4.8-6@0.3	Br<1 Sw:8,S no features or damage permitted
S30	3	30	99	99	4.8-6@0.3	Br<7 Sw:8,S no features or damage permitted
S20	4	20	99	99	4.8-6@0.3	Br<7 Sw:8,S no features or damage permitted
Export	5	20	60	60	0.8-3.5@0.03	Br<25 Sw:8,S,3 no features or damage permitted
Chip	6	42	54	60	2.6,5.2,7.8	Br<99 Sw:no restriction features and damage permitted

Appendix 1. Log grade specifications used in YTGen (201) software package to estimate log yields and revenues.

Feature codes given under conditions are in explained in Table 2.